

WindBots: persistent in-situ science explorers for gas giants

Completed Technology Project (2015 - 2016)



Project Introduction

We envision persistent exploration of the gas giants with robots powered by locally harvested energy, performing in-situ observational atmospheric science. Riding strong, turbulent windstorms of the troposphere, WindBots (WBs) tumble and are bumped around. Real-time control is used to adjust body shape/surface asymmetries for controlled aerodynamic forces, changing direction or lift. Autorotation and mechanisms similar to those used in kinetic/automatic watches are used to harvest wind energy. They obtain electric power via electromagnetic generators. They can also deploy retractable electrodynamic tethers to harvest the planetary magnetic field.

Anticipated Benefits

Cross-pollination: The concepts of energy harvesting studies in this proposal have similarities with efforts of harvesting wind and ocean energies on Earth, and will seek to engage and cross-pollinate with such efforts. **Inspire:** WB stimulates the thought of robotics researchers and student enthusiasts towards more harvesting of the wind, especially with the surge in new unmanned aerial vehicles (UAVs). **Outreach:** The NIAC presentations and final report will be made public and its summary published as NASA Technical Brief. We will disseminate the concept broadly, through a dedicated website and conference publications. A number of intern students will be engaged in this project. **Atmospheric Research:** WBs would be an excellent platform for the study of terrestrial hurricanes, to compensate the limitations of alternative solutions: planes can't fly below 3,000 feet because of extreme turbulence; dropsondes only provide a few minutes of data, and conventional UAVs, fragile designs, with little on-board power cannot survive long enough. In Sept 2014, NOAA has flown four Coyote UAVs into Hurricane Edouard, the first UAVs deployed inside a hurricane [NOA2014]; data was received, however the Coyotes were not recovered.



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Table of Contents

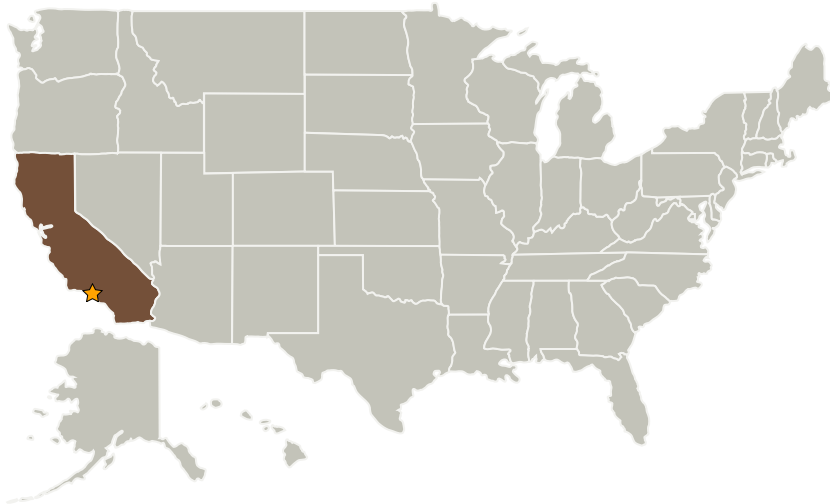
Project Introduction	1
Anticipated Benefits	1
Primary U.S. Work Locations and Key Partners	2
Project Transitions	2
Organizational Responsibility	2
Project Management	2
Project Website:	3
Technology Maturity (TRL)	3
Technology Areas	3
Target Destinations	3

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Primary U.S. Work Locations and Key Partners




Organizations Performing Work	Role	Type	Location
★ Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California
California Institute of Technology(CalTech)	Supporting Organization	Academia	Pasadena, California
University of California-Berkeley(Berkeley)	Supporting Organization	Academia	Berkeley, California

Primary U.S. Work Locations

California

Project Transitions

 **July 2015:** Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigators:Adrian Stoica
Masakazu Hirokawa**Co-Investigators:**Marcin L Witek
Georgios Matheou
Virgil Adumitroaie
Bruno M Quadrelli

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June 2016: Closed out

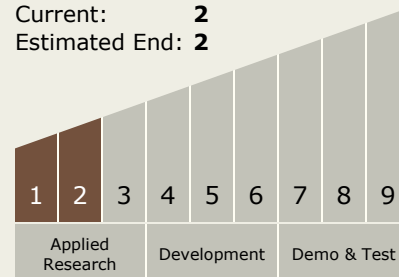
Closeout Summary: This report summarizes the study of a mission concept to Jupiter with one or multiple Wind Robots able to operate in the Jovian atmosphere, above and below the clouds - down to 10 bar, for long durations and using energy obtained from local sources. This concept would be a step towards persistent exploration of gas giants by robots performing in-situ atmospheric science, powered by locally harvested energy. The Wind Robots, referred in this report as WindBots (WBs), would ride the planetary winds and transform aeolian energy into kinetic energy of flight, and electrical energy for on-board equipment. Small shape adjustments modify the aerodynamic characteristics of their surfaces, allowing for changes in direction and a high movement autonomy. Specifically, we sought solutions to increase survivability to strong/turbulent winds, and mobility and autonomy compared to passive balloons. **MAIN FINDINGS** We examined Jupiter atmospheric characteristics and options of WB mobility. The optimal region both for science and operations was determined between 0.3 bar and 10 bar, within which all areas of known clouds is included. Based on the atmospheric movement, the stormy region of the Great Red Spot (GRS) and the region north-west of it, in the South Equatorial Belt, have the highest variability of wind vectors, and thus, so far, appear to be the most attractive part of Jupiter for placing a first WindBot mission. We examined various types of buoyancy control and energy use through static and dynamic soaring. We reviewed various solutions of aerostats, wing-based designs, an inflato-glider, reconfigurable wings, foldable and collapsible or expandable structures with various shell forms in airships. We also looked at airborne extensions of surface mobility powered by the wind (Moballs, Tumbleweed, Mars ball, Spherobot). The lowest risk solution to providing high atmospheric mobility, covering long distances in a Jovian zone, e.g. South Tropical Zone, is the buoyant hydrogen-based inflatable design, with a diameter exceeding 70m, and with control mechanisms for enhanced mobility. Gliders with L/D factors over 70 could also potentially survive long duration flight in the target region of interest between 0.3 bar and 10 bar, provided several challenges in automated detection and navigation to obtain lift from updrafts are overcome. For exploration in stormy regions of higher turbulence (as observed at planetary scale) e.g. riding the upward currents in the eyewall of the GRS, gliders with an L/D of only 24, could also satisfy the requirements provided they solve the localization problem and timely move towards the updrafts; a higher level of intelligent autonomy is needed in the case of the GRS. A hybrid, inflatable design with wing, or other control surface, may be potentially the solution with the highest risk yet also highest payoff. We considered various options to harvest energy for operations. We analyzed vertical updrafts/thermals and horizontal components of the wind, and ways to convert wind energy into electrical energy. Both 1) the conversion of mechanical energy from rotors pushed by air flow, such as in autorotation, in updrafts or horizontal gusts, and 2) use of energy from vibration, were found effective. Harvesting hydrogen for fuel cells may be valuable for shorter duration missions. **RECOMMENDATION** We propose to refine a mission concept to Great Red Spot, continuing the study of two alternate designs: an adaptive wing glider and a lightweight (possibly hydrogen-based buoyant) design with controllable surfaces.

Project Website:

<https://www.nasa.gov/directorates/spacetech/home/index.html>

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **2**



Technology Areas

Primary:

- TX04 Robotic Systems
 - TX04.2 Mobility
 - TX04.2.2 Above-Surface Mobility

Target Destinations

The Moon, Outside the Solar System